

SEQUENCE IN WELDED SHIP
DESIGN AND CONSTRUCTION.

by

M. N. Pieter Hinkamp.

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SEQUENCE IN WELDED SHIP DESIGN AND CONSTRUCTION

M.N. Pieter Hinkamp

Lieut. Comdr., U.S.N.

May, 1948.

Carnegie Institute of Technology
Pittsburgh, Pennsylvania

RESEARCH IN WIND TUNNELS AND CONSTRUCTION

W. E. Baker, M.S.
Ph.D., U.S.N.
May, 1961

SEQUENCE IN WELDED SHIP DESIGN AND CONSTRUCTION

The problems in design and construction of ships are somewhat different from the problems confronting the designers of land structures such as bridges and buildings. Water-tightness, smallest possible deadweight tonnage consistent with the required dimensions, and extreme conditions of stress encountered in hogging and sagging in heavy seaways, are the outstanding special problems. Since the introduction of mild steel, in lieu of wrought iron, as the principal material in ship construction, the scantlings (sizes of plates and frames in shipbuilding) have been reduced and the designs simplified, in general. Riveted construction had progressed to the limit where further simplifications and reductions in scantlings would impair the seaworthiness of the vessel. The advent of welding, as the method of fabrication, changed the whole picture and opened up many possibilities for economies in construction as well as being the means of approaching the ideal joint.

It was essential for ship builders to revise their thinking, away from the old conventional methods of shipbuilding, whereby each piece of the vessel was assembled on the building ways, to the modern concept of final assembly of prefabricated units or sections. The recent war, with its unprecedented demand for ships, afforded added impetus to this concept. Some of the early experiences of shipyards, accustomed to riveted construction, were unfortunate when they attempted all welded construction. Warpage, distortion, dimensional instability, and

serious fractures were the common ailments.

As an aid in visualizing the modern concept of ship construction, the following outline of the procedure used in the construction of a typical cargo vessel will be helpful:-

1. Planning and design for welded construction.
2. Fabrication of plating and framing by flame cutting and beveling of edges where necessary. (to be done in the shops.)
3. Construction of sub-assemblies of as large a size as the yard facilities will permit. (to be done on slabs and under cover, when possible)
4. Erection of these sub-assemblies into sections.
5. Final assembly of the sections on the building ways.

With the above outline in mind, it is possible to imagine the desirability of a well-planned sequence of operations to ensure a smooth flow of materials, elimination of useless work, and the logical erection of the vessel. A little less obvious, but perhaps even more important from the standpoint of the seaworthiness of the completed ship, is the elimination of the previously mentioned troubles by proper welding and erection sequence. It is the purpose of this paper to present a discussion of the reasoning behind the sequence and to show how it is applied in the yards to build stress-free, dimensionally accurate, all-welded ships. The type of ship discussed will be limited to cargo ships, but the principles could be applied to any welded vessel. It is desired to point out that an all-welded ship is monolithic in character, as contrasted with riveted ships. As a

regions traversed were the common elements.

As an aid in visualizing the various concepts of ship construction, the following outline of the procedures used in the construction of a typical cargo vessel will be helpful.

1. Planning and design for related construction.
2. Fabrication of plates and framing by flame cutting and bending of edges where necessary. (to be done in the shops.)

3. Construction of end-assembly of as large a ship as the yard facilities will permit. (to be done on slips and water ways, when possible)

4. Division of these end-assemblies into sections.
5. Final assembly of the sections on the building ways.

With the above outline in mind, it is possible to determine the feasibility of a self-planned sequence of operations for various types of materials, utilization of resources.

work, and the logical sequence of the vessel. A little time spent

view, but perhaps even more important from the standpoint of the construction of the completed ship, is the utilization of the previously mentioned facilities for proper welding and erection

equipment. It is the purpose of this paper to present a discussion of the reasoning behind the sequence and to show how it is

applied in the yards to build steel-hulled, discontinuously welded, all-welded ships. The type of ship discussed will be limited

to cargo ships, but the principles could be applied to any vessel. It is desired to point out that an all-welded ship is

comparable in operation, as contrasted with riveted ships, as a

consequence, welded ships are considerably stiffer, an important consideration in seagoing qualities.

Distortion;-

Distortion, the twisting or bending of a structure out of the regular or intended shape, is the greatest obstacle to overcome in welded ship construction. Residual stress, locked-in stress, and warping will be essentially eliminated if the ship is built with a minimum of distortion. When a ship is welded, there is a tendency for the bow and stern to lift off the blocks, and for the bilges to rise. There have been some extreme cases of this effect. Distortion also causes poor underwater lines, thus seriously affecting the ship's handling characteristics. Another bad effect is departure from the specified dimensions of the ship, i.e. length and beam.

The residual stresses resulting from the ship being built where distortions are present, or where distortions have been forcibly corrected, are often quite high and constitute a serious pre-loading of joints and structure.

The principal cause of distortion is shrinkage due to welding, although there are other causes such as:-

1. storage and handling distortions.
2. flame cutting and shrinkage.
3. improper fitting.
4. unequal expansion due to the sun's rays or atmospheric conditions.
5. over shrinking, (over-correction for distortion).

consideration in various countries, with ship and machinery alike, in various countries.

Distortion

Distortion, the twisting or bending of a structure due to the action of intended stress, is the principal cause of failure in welded ship construction. Distortion occurs in all cases, and welding will be essentially eliminated if the ship is built with a minimum of distortion. When a ship is built, there is a tendency for the bow and stern to lift off the keel, and for the bilge to rise. There have been many cases of this effect. Distortion also causes poor water-tightness, and seriously affects the ship's handling characteristics. Another bad effect is departure from the intended dimensions of the ship, for length and beam.

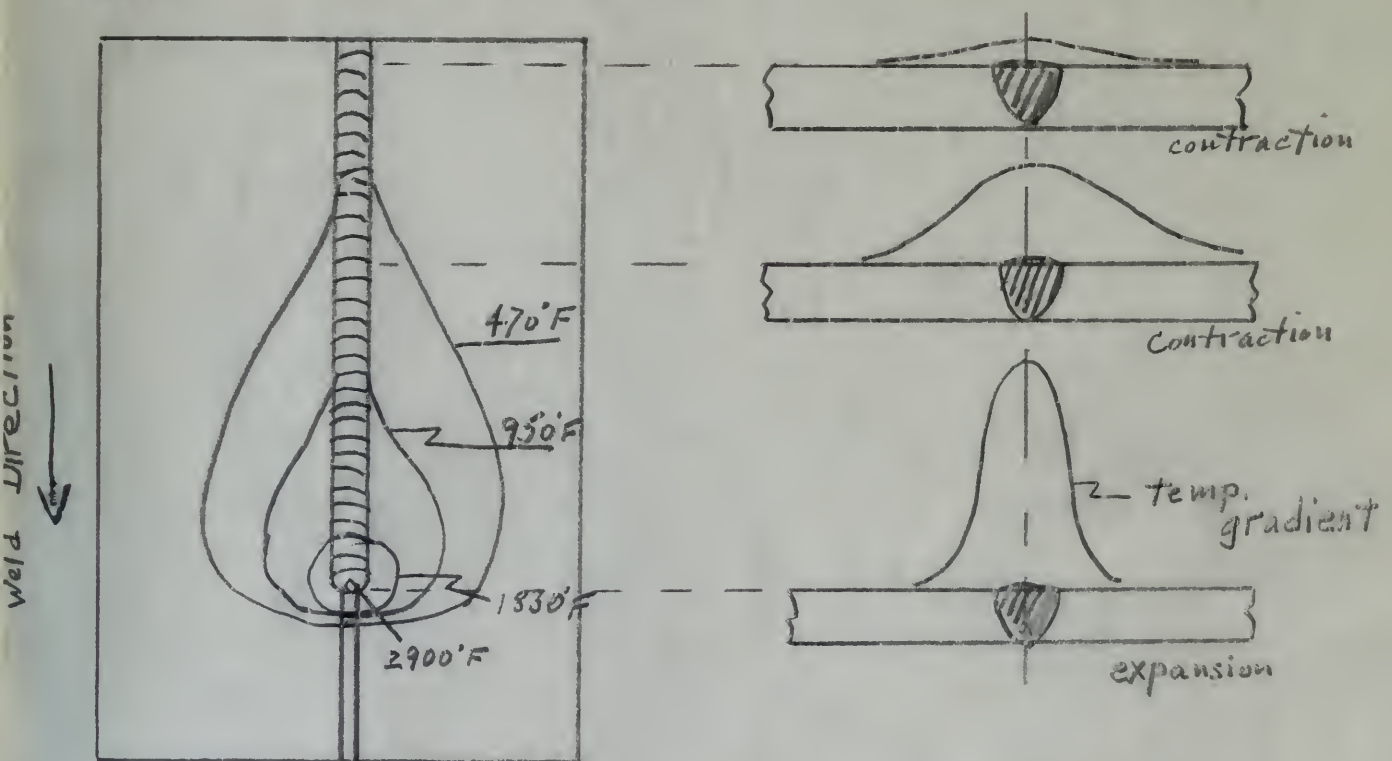
The principal stresses resulting from the ship being built are those due to the weight of the hull, the weight of the machinery, and the weight of the cargo. These stresses are resisted by the strength of the hull and the strength of the machinery. The principal cause of failure is the distortion of the hull and the machinery.

- The principal cause of distortion is the weight of the hull and the machinery. The following are the principal causes of distortion:
1. Weight of the hull and machinery.
 2. Weight of the cargo.
 3. Weight of the machinery.
 4. Weight of the cargo.
 5. Weight of the machinery.
 6. Weight of the cargo.

Welding and erection sequences constitute the proper means to correct distortion, although it is possible to make force fits, heat to expand a local area and then quench, peening, and other even less desirable methods. To understand how distortion comes about, and why sequence is so important in eliminating it, the following section will go into the effects of expansion and contraction in the welding process.

Expansion and Contraction;-

When metals are heated they expand and when cooled they contract. Not only the weld metal itself, but also the base metal, which is being joined, follows this law. An illustration of the temperature gradients to be expected as a bead is laid, follows:-



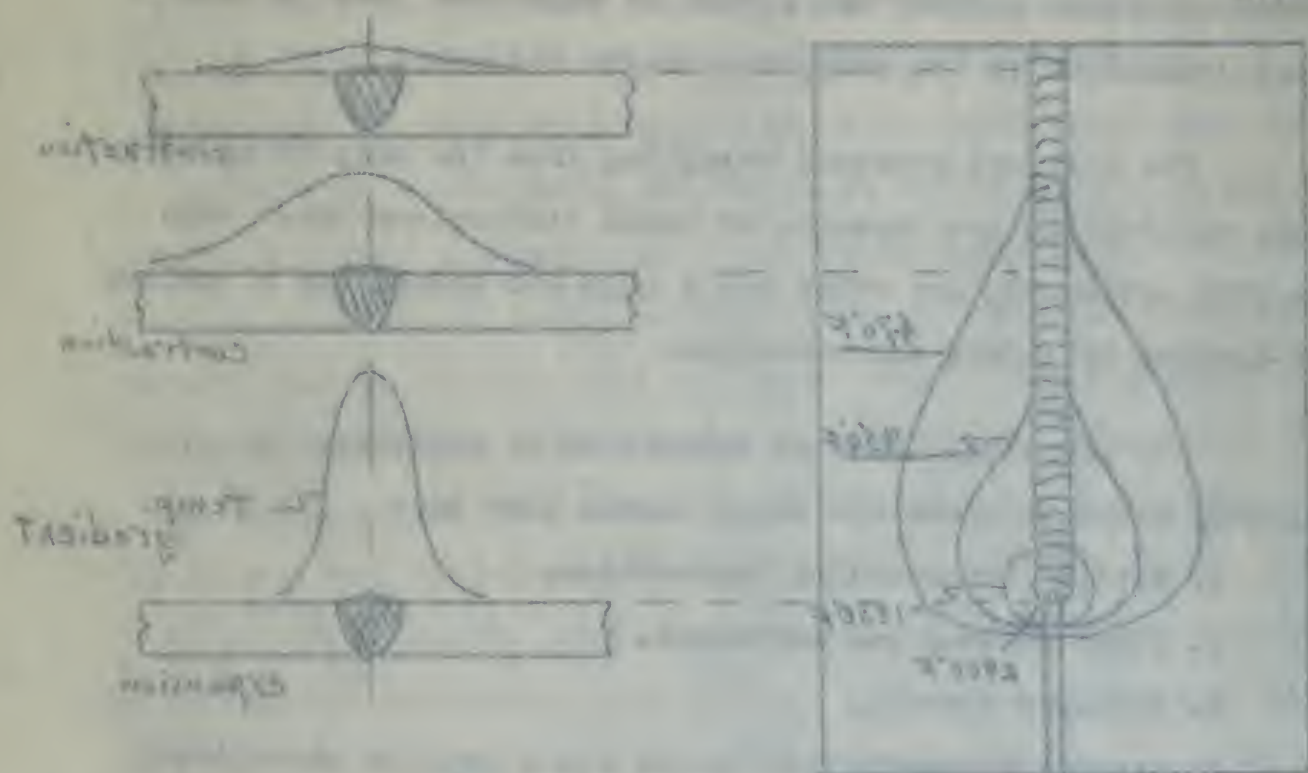
This illustration is for the case of unsupported plates, but it

Welding and welding processes are classified as proper means for control of distortion, although it is possible to cause some distortion, but to expand a local area and then contract, then the distortion is less. To maintain low distortion some effort, and any expansion is so important in welding it, the following section will be made for the purpose of expansion and contraction in the welded process.

Expansion and Contraction:-

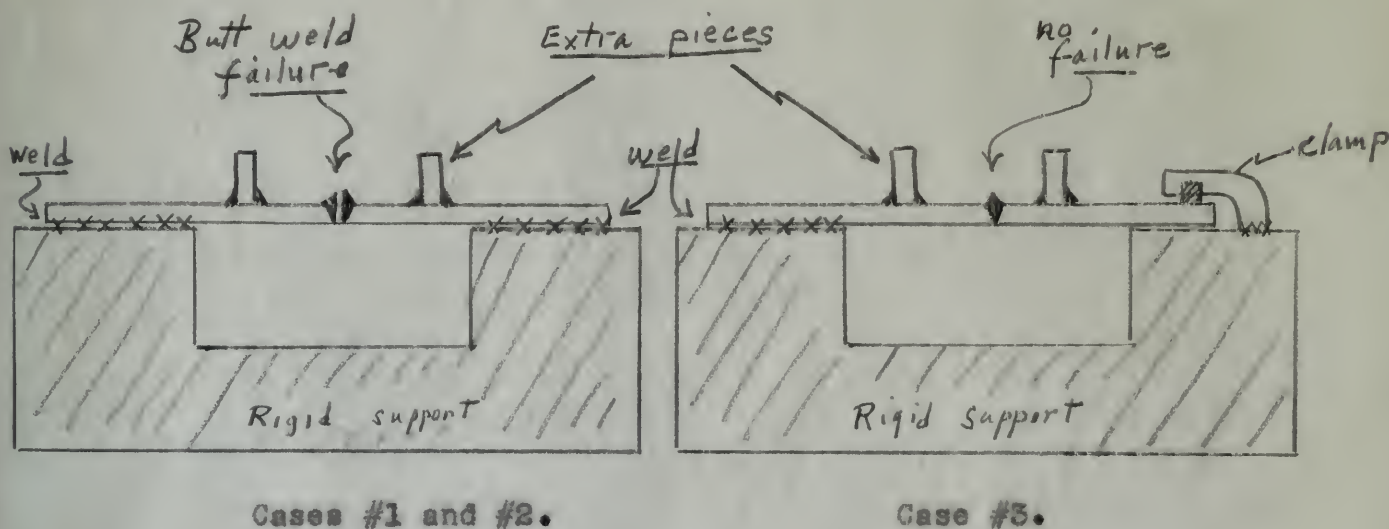
When metals are heated they expand and when cooled they contract. Not only this metal itself, but also the base metal, which is being joined, follows this law. In illustration of the temperature gradient is to expand as a metal is heated, this

Figure:-



This illustration is for the case of a single weld, but it

is easy to see what would be the case if the plates were restrained during this heating and cooling period cycle. The final result would be an overall contraction in the plane of the plate, perpendicular to the bead, due to the contraction of the weld metal, whose expansion on heating was resisted by the restrained plates, thus setting up a condition of residual stress, or else resulting in distortion as a means of relieving the stress. The following sketches show the results of unrestrained and restrained welding:-

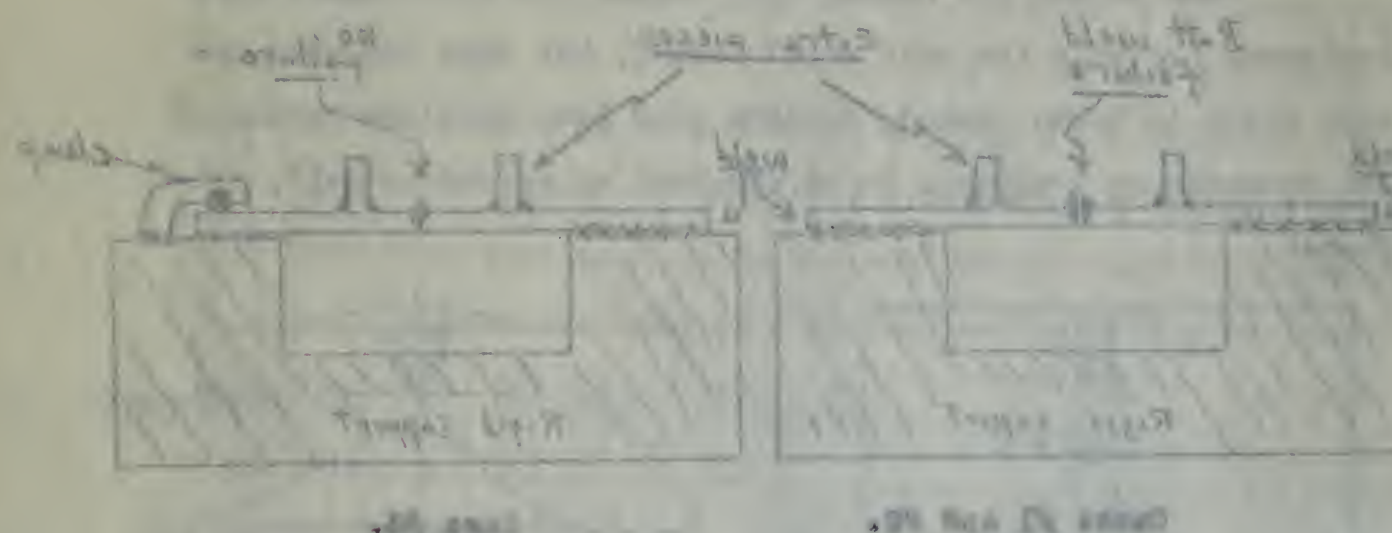


In case #1, two members were welded while both were entirely restrained, resulting in fracture of the butt weld due to the weld contraction. In case #2, the butt weld held, and then two extra members were welded onto the pieces, as noted, resulting in fracture of the butt weld. In case #3, one end was firmly anchored by welding, while the other end was clamped in such a manner as to allow some freedom of movement. The butt weld did not fail.

The above reasoning leads to a fundamental rule: Leave one end of a member or structure free to contract towards the

is easy to see what would be the case if the plates were restrained
 as during plate bending and cooling twisted again. The final results
 would be an overall contraction in the plane of the plate, corres-
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 whose expansion on heating was restricted by the restrained plates,
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 ing in distortion as a means of relieving the stress. The follow-
 ing sections show the results of unrestrained and restrained

results:-



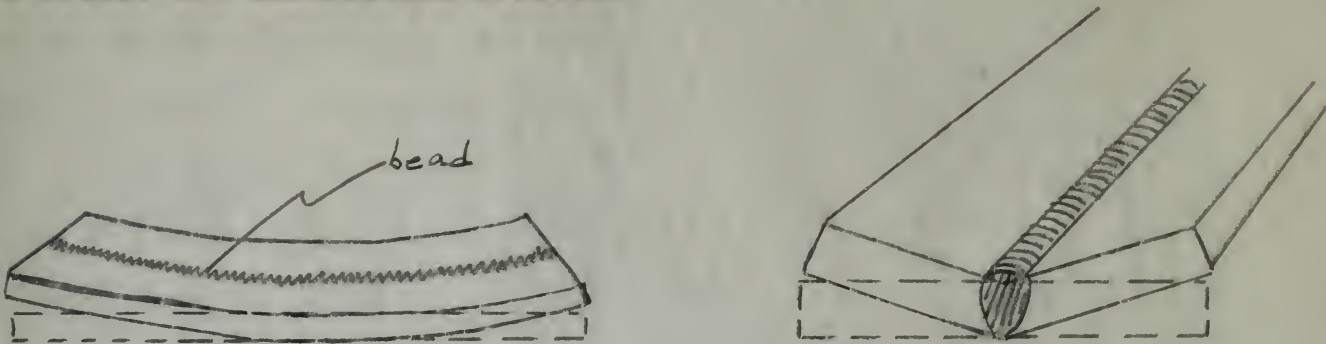
In case VI, two supports were welded with both ends entirely re-
 strained, resulting in distortion of the butt weld due to the weld
 contraction. In case VII, the butt weld joint, and when two re-
 straints were welded with the plates, as shown, resulting in dis-
 tortion of the butt weld. In case VIII, one end was freely supported
 by welding, while the other end was clamped in such a manner as
 to allow some freedom of movement. The butt weld did not twist.

The above sections lead to a fundamental rule; namely

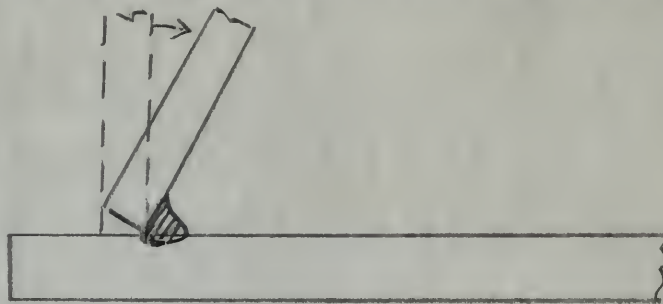
one end of a member or structure free to contract towards the

point of welding. This rule must be considered in design and planning as well as by the welders and shipfitters.

Warping is primarily caused by the heating effects due to welding. When a bead is laid on a flat plate, the plate will warp as shown below, if it is not restrained or not heavy enough to resist the contraction forces:-



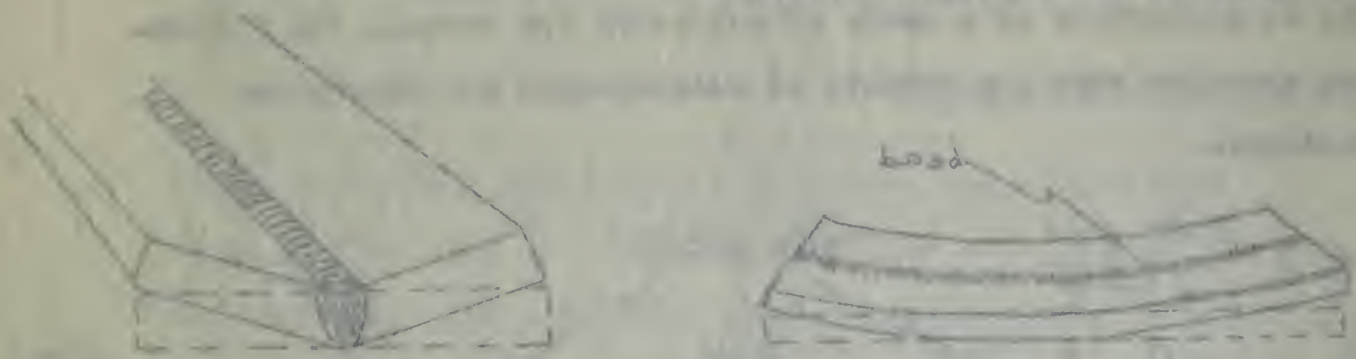
Another example of warping is that caused in welding a Tee joint:-



When two plates with an opening between them are welded, the plates will draw together as the welding progresses, and the amount will depend on the speed of welding and on the type of electrodes. Slow rate of travel and bare electrodes will cause greater drawing together. With shielded arc electrodes and very rapid travel, the plates may even separate on welding but will still come together when cooled. The initial separation is caused by less total heat input and the protective coating, over the bead, acting somewhat

of welding, this will be considered in design and
as well as by the welder and his assistants.

Warping is primarily caused by the heating effects due
to welding. When a bead is laid on a flat plate, the plate will
warp as shown below, if it is not restrained or not heavy enough
to resist the contraction forces.

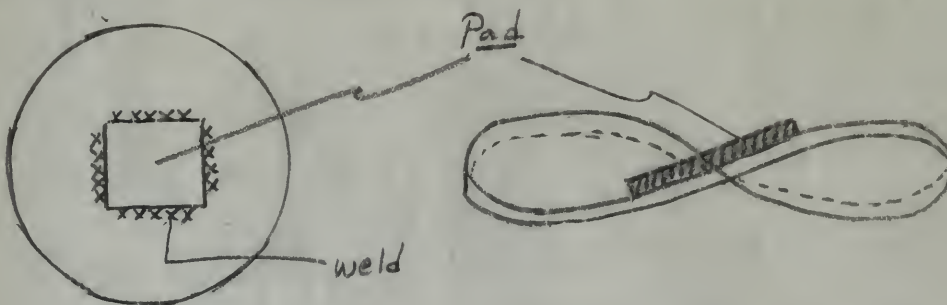


Another example of warping is that caused in welding a Tee joint:-



When two plates with an opening between them are welded, the plates
will move together as the welding progresses, and the opening will
depend on the speed of welding and on the type of electrode. Slow
rate of travel and low amperage will cause greater drawing
together. Also, plates are distorted and may warp (travel), the
plates may even separate on welding and will still come together
when cooled. The initial separation is caused by heat local heat
input and the protective gas, over the weld, being expanded

as an insulator. If the seam is long, tack welds are desirable to maintain some degree of correct positioning of the plates. Further, if the plates are beveled for manual welding, there will be a tendency for the plates to bend upwards around the weld bead. The amount of this warping is directly dependent on the number of passes, which indicates that it is desirable to complete the weld with the minimum number of passes and the minimum amount of weld metal. Another frequently encountered case of warpage is when a pad is welded to a circular disc. This is illustrated below:-



If, however, the circular plate had been clamped or weighted in such a manner as to partially restrain movement in a vertical direction, then the plate would have been flat when the weld was completed.

The above illustrations of tack welding and clamping give a second fundamental rule: Warpage may be prevented through partial restraint by clamping or weighting the members down. This rule is particularly applicable to the fabrication of the sub-assemblies on the flats or slabs, where jigs, dogs, and weights are available. When applied to the main erection of large sections or to the final assembly, the use of strongbacks, and other means of bracing, accomplish much the same result.

as an indicator. If the seam is long, each welder may determine to maintain some degree of correct positioning of the plates. However, if the plates are covered for manual welding, there will be a tendency for the plates to bend upwards toward the weld metal. The amount of side warping is directly dependent on the number of passes, which indicates that it is desirable to minimize the weld with the minimum number of passes and the minimum amount of weld metal. Another frequently encountered cause of warpage is when a weld is welded to a circular plate. This is illustrated below:



If, however, the circular plate had been clamped or welded in such a manner as to partially restrain movement in a vertical direction, then the plate would have been flat when the weld was completed.

The above illustrations of back warping and twisting are a second fundamental factor which may be prevented through partial restraint of clamping or welding the members down. This rule is particularly applicable to the fabrication of the assemblies in the form of rings, where light, open, and welded are available. When applied to the main sections of large sections as to the final assembly, the use of supports, and other means of bracing, especially when the same results.

The use of jigs and other means of restraining warpage will most likely leave large residual stresses within the fabricated part. There are three possibilities concerning the relief of these stresses:-

- a. The part will warp when removed from the jig.
- b. The weld will crack.
- c. The weld or adjacent plate will yield plastically.

Residual stresses may remain in the part only up to the yield point without some plastic deformation occurring. It should be noted that with the mild steels (.20C on the average) used in ship building, unless the restraint is severe, the plate or bead will yield plastically to relieve severe residual stress, without suffering any loss in ultimate strength upon future reloading.

It has been found that residual stresses remaining below the yield point will not be appreciably relieved in service. On the other hand, it has been determined, in general, that residual stresses do not contribute appreciably to the failures of welded ships at sea, unless there is a localized bad combination of residual stresses, some form of notch present, and severe loading. In passing, it might be well to note that the primary cause of the failures of welded ships is brittleness of the steel, induced by the multi-axial stress system acting at the base of the notch. The notch may be one caused by poor geometrical design of the vessel, (square shear^e strake cut-outs, for example) or by poor workmanship (defects in the weld or incomplete penetration). The above is aggravated by notch-sensitive steel, especially at low temperatures.

The use of this and other means of restraining weapons
will most likely leave large residual weapons within the sub-
jected areas. There are three possibilities concerning the
effect of these weapons:-

- a. The land will stay where it was from the 1st.
 - b. The land will break.
 - c. The land on adjacent areas will yield plastically.
- Residual weapons may remain in the first only or in the field
points without some plastic deformation occurring. It should be
noted that with this area (1000 on the average) land is
very soft, unless the residual is severe, the yield on land
will yield plastically to relieve some residual stress. With
one relieving the land in ultimate strength from future reloading.

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ed steel at sea, unless there is a localized and complex of
residual stresses, some form of notch present, and severe load-
ing. In practice, it might be well to note that the primary source
of the failure of welded joints is brittleness of the steel, in-
duced by the mill-scale stress system existing at the back of the
joint. The notch may be one caused by poor metallurgical design or
the vessel, (perhaps even stress not shown, for example) or by
over workmanship (defects in not weld or incomplete penetration).
The above is summarized by Miller-Schiffman et al, especially at
low temperatures.

Development of Welding Sequence to Control Shrinkage:-

Since it has been shown that the major contribution to distortion is weld shrinkage, this section will deal with the means by which shrinkage is kept under control. The basic ideas of welding sequence will be developed in the discussion.

The amount of weld shrinkage is governed by several factors:-

1. The amount of heat that a welder uses for a given size rod and weld.
2. The rate of travel along the weld.
3. The root opening and the weld size.

The most efficient welds are made by using, (1), as large a size electrode as possible, (2), high current, and (3), fast travel. All these factors signify that less shrinkage will be had, due to less heat input into the weld. This method of welding will also result in deeper penetration, with a consequently greater heat penetration to the reverse side of the weld, resulting in less warping, due to the thermal gradient. It is to be noted that the major shrinkage in manual welding is at right angles to the direction of welding. The shrinkage, in the direction of welding, is negligible.

Some of the ways in which shrinkage can be controlled or counteracted:-

1. care in fitting.
2. use of the wandering procedure of welding.
3. use of the back step procedure in welding.

Development of White House to Control Government

of saided reference will be developed in the discussion.

The amount of solid ammonia is converted by several factors

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1. The amount of heat that a walling space has a direct effect on the amount of heat that is lost.

2. The cost of travel along the wind.

of welding. The advantage, in the direction of welding, is dis-
advantage in manual welding is at right angles to the direction
of the central treatment. It is in the noted that the ap-
proach to the reverse side of the weld, resulting in less welding,
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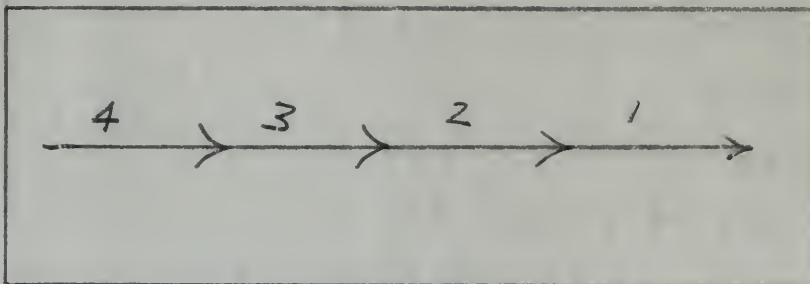
1. Name of the person
2. Date of the meeting
3. Name of the person

4. use of partial restraints.
5. keeping the welding evenly balanced both vertically and horizontally.
6. by various post-welding treatments, such as peening or annealing.
7. erection by sub-assemblies.

Only those ways which relate to sequence will be further discussed.

The wandering procedure is the running of short bead increments at random throughout the structure. This spreads the heat over the entire structure and lowers the general level of heat. It is interesting to note that there may be considerable rise in the temperature of a structure and consequent distortion if there are too many welders working on it, especially in a concentrated locality.

Back-step procedure is very effective and is illustrated by the following sketch:-



Note that the directions are reversed to the general direction of travel. It is very important to have good fusion with each succeeding bead increment. Another variation of this method is the skip-step-back weld which is used to join sections where

4. use of partial variables.

5. keeping the writing evenly balanced both vertically

and horizontally.

6. by various post-writing methods, such as peeling

or erasing.

7. erasing by sub-assembly.

Only those ways which relate in sequence will be further discussed.

The working procedure is the meaning of about half in-

crease in width throughout the elements. This shows the

need over the entire structure and hence the general level of

work. It is interesting to note that there may be considerable

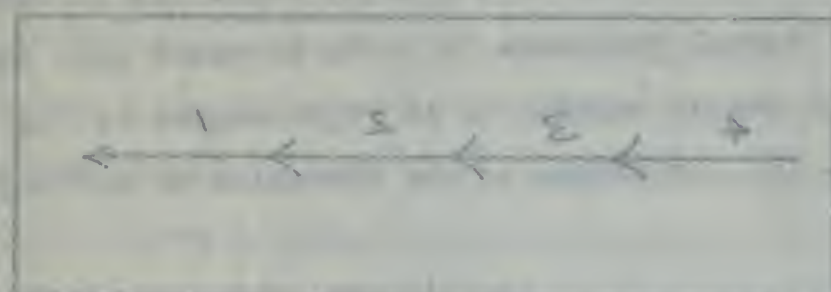
variation in the temperature of a structure and consequent distortion

if there are too many without working on it, especially in a

concentrated locality.

Each-step procedure is very effective and is illustrated

by the following example:-



Note that the direction is reversed in the general direction

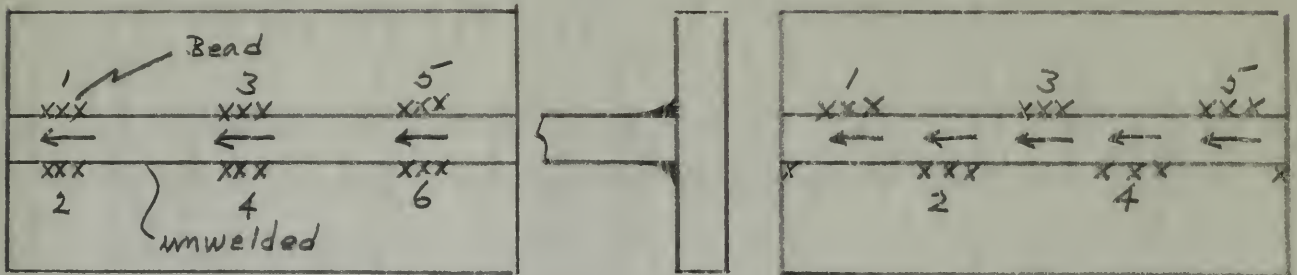
of travel. It is very important to have good lines with each

preceding and intervening. Another variation of this method is

the step-step method which is used to join features where

the loading is not ~~important~~ critical or watertightness is not important. Note the sequence of laying the beads. This sequence may be varied somewhat:-

("Tee" joint)



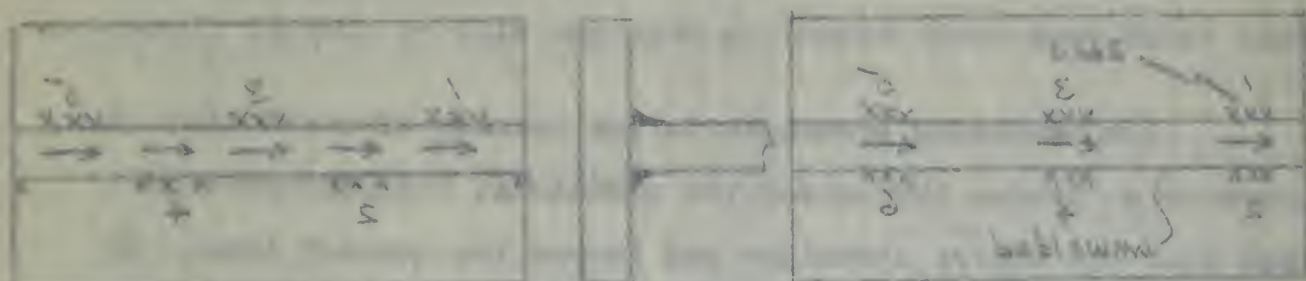
The important idea so far noted in regard to sequence, is the reduction of weld bead shrinkage effects to reduce distortion.

The next point is keeping the welding evenly balanced out on either side of a structure when welding. By evenly balanced it is meant using welders on either side of the structure, performing identical operations simultaneously. This is particularly important in long structures, in which the wandering sequence may be used, or else the welding should start at center and progress outwards. This will become more apparent when applications are discussed later on.

The erection by sub-assembly is a potent means of combatting shrinkage troubles. The sub-assemblies are made up of pre-fabricated parts, which have already contracted when each was welded, and thus their individual contractions will not af-

The leading is not important in the case of the leading is not important. The sequence of laying the leads. The sequence may be varied somewhat.

(Two Lead)



The important thing to be noted in regard to sequence, is the reduction of self-heating effects to reduce distortion.

The next point is keeping the winding evenly balanced out on either side of a structure when winding. By evenly balanced it is meant that the leads on either side of the structure, performing identical operations simultaneously. This is particularly important in long structures, in which the number of leads may be large, so that the winding should start at one end and proceed towards the other. This will insure even winding and distortion will be avoided.

The question of non-uniformity in a point means of even winding should be avoided. The non-uniformities are made up of the individual leads, which have already mentioned when each are wound, and the final individual sections will not be

fect the fabrication of the sub-assembly. This remark assumes that shrinkage will not be so great as to cause poor fit-up and subsequent introduction of high stresses by making force fits. A similar situation holds in regard to the final assembly of the sub-assemblies on the building ways.

In summary, the fundamentals of welding sequence are:-

1. Plan to reduce the heat input to a minimum and to distribute the heat throughout the structure, when considered as a whole. This involves wandering, skip welding, or backstep.
2. Balance out the welding from side to side of a structure.
3. Start welding a structure, such as the final erection of the sub-assemblies, from the bottom center and work outwards and upwards, leaving the ends free until the last.

Design and Planning for Sequence:-

It is a recognized fact that erection and welding sequences are not inseparable, and, therefore, in designing and planning they should be coordinated. Draftsmen should be familiar with proper welding practices as well as structure design. To build a sound welded ship, which embodies all the advantages of welded construction, the welding and erection sequences must be worked out in detail and presented in a logical manner to the supervisory force of the shipyard. There is no such thing as too much detail in stating the sequences.

test the efficiency of the sub-assembly. This means means that
 drawings will not be used as a basis for the design and con-
 struction of the sub-assembly by using force fits. A
 similar situation exists in regard to the final assembly of the
 sub-assembly on the building frame.

In summary, the fundamental of welding requires that
 1. When in position the work piece is a minimum and to
 distribute the heat throughout the assembly, when
 considered as a whole. This involves welding,
 strip welding, or bolting.
 2. Remove the welding from side to side of a
 structure.

3. Start welding a structure, such as the final struc-
 ture of the sub-assembly, from the bottom center
 and work upwards and outwards, leaving the ends
 free until the last.

Design and Details for Welding

It is a recognized fact that welded and welded as-
 semblies are not interchangeable, and, therefore, in designing and
 planning they should be considered. Problems should be con-
 sidered after proper welding practices as well as structure de-
 sign. To make a sound welded strip, which connects all the
 advantages of welded construction, the welded construction
 should be designed and detailed in a
 logical manner to the superstructure of the building. There
 is no such thing as a welded detail in building the building.

if the total distortion and residual stresses in the hull are to be kept at a minimum. Even with recognized good design and planning, there is an over-all allowance made for shrinkage which, in a cargo vessel, amounts to 1 inch / 100 feet of length and 1 inch from the designed molded beam. The deviation from the true measurements is checked from time to time by surveying, and, if the deviation is too large, steps are immediately ^{taken} to remedy it.

A very important point in planning a sequence is to analyze what influence warpings will have on the hull as a whole, and then to divide the hull up into bays which are to be welded in a sequence, such that the stresses and warping arising will counteract each other. The sequence of welding must also be planned such that the members have freedom of motion along the designed lines of the ship so as to minimize distortions from the desired underwater form. As an aid to the above, one shipyard has developed the method of making a transparent plastic model of the ship, to exact scale. The model is built up in the desired sections and sub-assemblies, which can be disassembled for detailed study, later. The model is used for final planning of sequences and for instructing the supervisory personnel. As a sidelight of this model idea, it is possible to very greatly increase the ^{amount of} automatic welding possible to perform on the hull, due to the ease with which favorable situations for it can be visualized. The same reasoning applies to the development of jigs and fixtures allowing a maximum of down-hand welding. These points add greatly to the economy and increase the seaworthiness of the vessel.

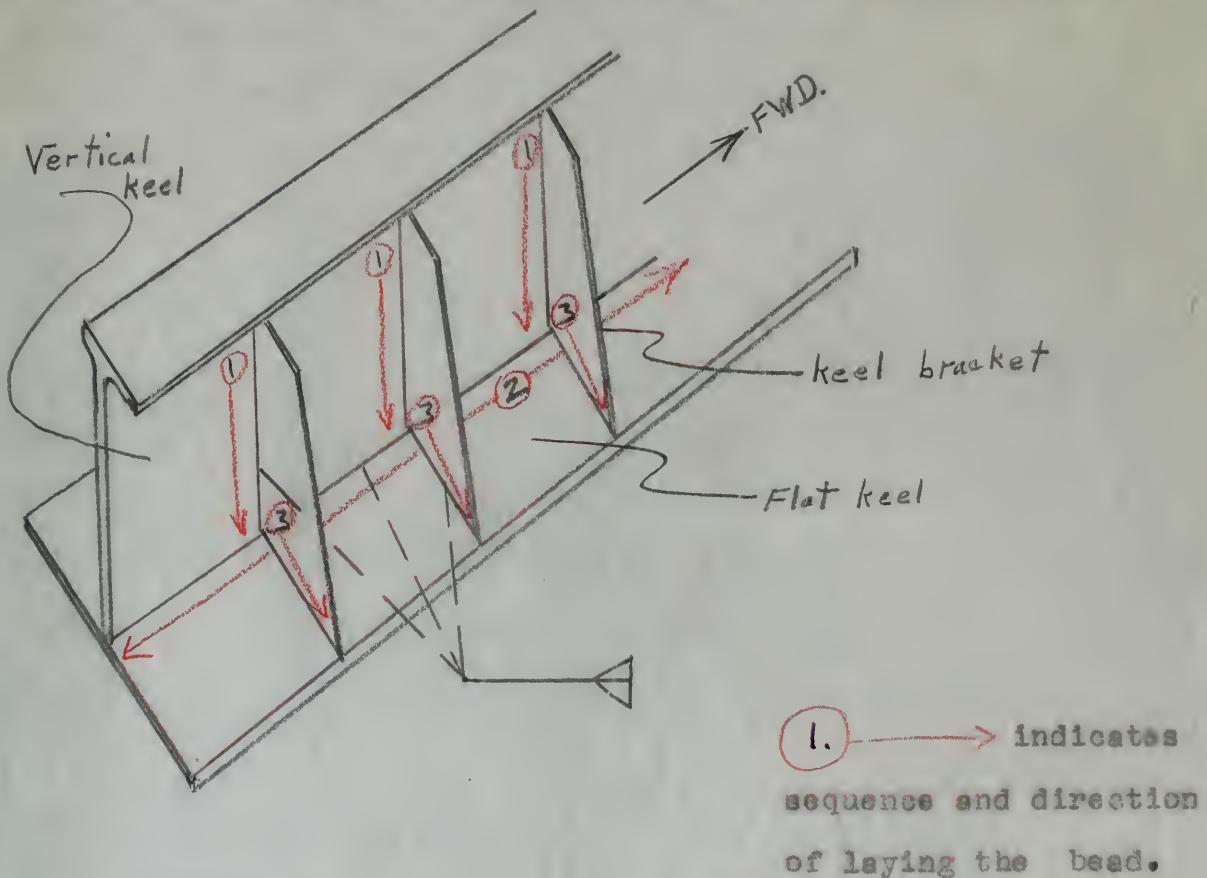
At the total distortion and residual stresses in the hull are to be kept at a minimum. When with reinforced steel design and this thing, there is an over-all alignment made for structural steel, in a cargo vessel, normally to 1 inch / 100 feet of length and 1 inch from the designed loaded beam, the deviation from the true measurement is divided from that to size by surveying, and, if the deviation is too large, there are immediately to remedy it.

A very important point in planning a sequence is to make the most influence regarding will have on the hull as a whole, and then to divide the hull up into parts which are to be welded in a sequence, such that the stresses and welding sequence will be continuous and each step. The sequence of welding must also be planned such that the members have freedom of motion along the welded lines at the ship as to eliminate distortion from the desired uniform water form. As an aid to the above, one shipyard has developed the method of making a transparent plastic model of the ship, in exact scale. The model is built up in the desired sections and sub-sections, which are then assembled for detailed study later. The model is used for final planning of sequence and for illustrating the supervisory personnel. As a sidelight of this model idea, it is possible to very greatly increase the welding possibilities to perform on the hull, due to the use with which favorable situation for it can be visualized. The same principle applies to the development of steel and structural steel for a section of steel-hull vessel. These points and greatly in the economy and increase the soundness of the vessel.

Applications of Welding and Erection Sequence:-

As can be seen from this paper, the idea of sequence grew up as a result of practical experience and empirical knowledge. Soon, however, the scientific reasoning of welding engineers arrived at the basic fundamentals previously noted. It is of interest to see how these principles are applied in one or two actual cases.

For the first case, a simple sub-assembly of a longitudinal keel section will be taken. The following sketches will illustrate the fundamentals as applied to this type of sub-assembly:-



Back-step all beads.

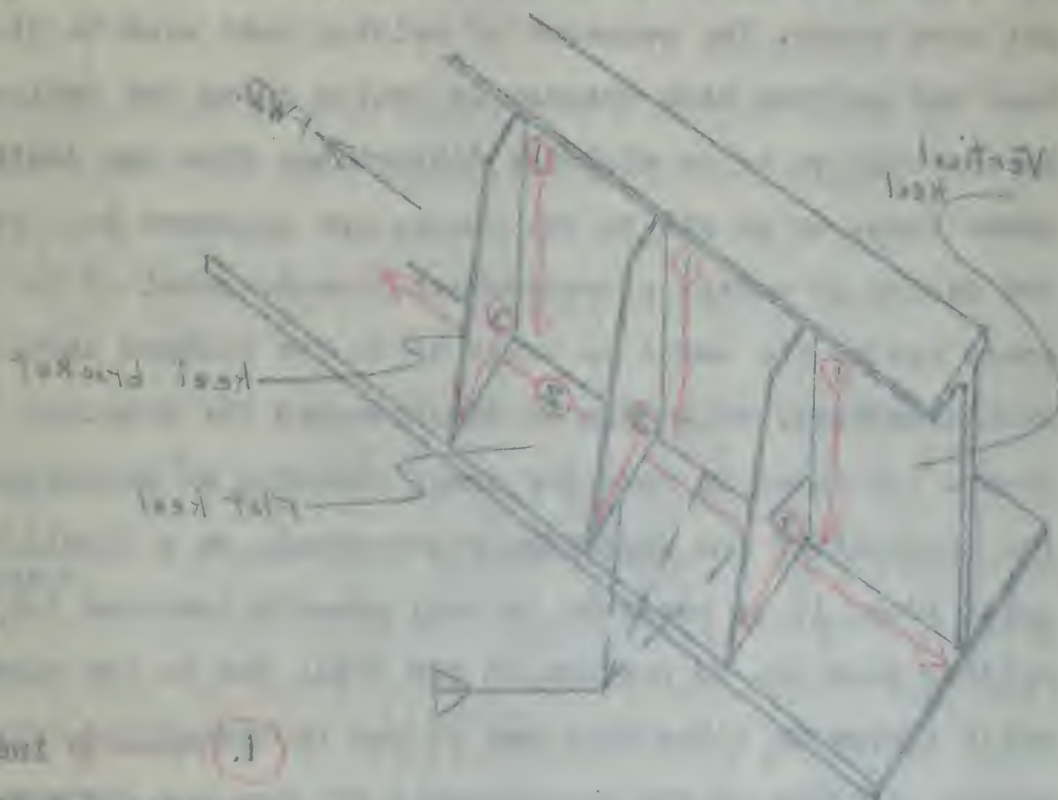
1. Weld opposite side brackets simultaneously.

Tack down as required.

Application of Walling and Retention Principles

As can be seen from this paper, the idea of applying the principles of walling and retention to the design of a structure is not new. However, the principle of applying the principles of walling and retention to the design of a structure is not new. It is of interest to see how these principles are applied in one or two actual cases.

For the first case, a simple sub-assembly of a longitudinal beam section will be taken. The following sub-assembly illustrates the principle as applied to this type of sub-assembly:



(1) indicates
position and direction
of the beam.

Each case is typical.
(1) With opposite side members simultaneously.
Each case is typical.

- ② Start welding at center of keel sections. Weld fore and aft short lengths alternately. Weld port and starboard simultaneously. Do not tack down more than one bracket ahead of welding.
- ③ Weld opposite side brackets simultaneously.

Welding of the brackets to both the vertical and the flat keels must be kept evenly balanced, and the heating of the vertical keel must be evenly distributed from top to bottom to maintain alignment. This latter is done by the use of back-step welding. Care must be exercised in tacking down too far ahead of the point where welding is being done or else warpage will result, due to the uneven distribution of stresses. Despite such care, it is often necessary to bow down a keel sub-assembly to offset contraction between top and bottom of the keel assembly.

The second example will illustrate one sequence, in which two sections are joined together on the building ways. The sequence presented here is typical of the hull work done on the building ways. It is to be remembered in this case that the bulkhead section pictured is the boundary between two pre-fabricated hull sections and is thus in a vertical position, which precludes the use of an automatic welding machine.

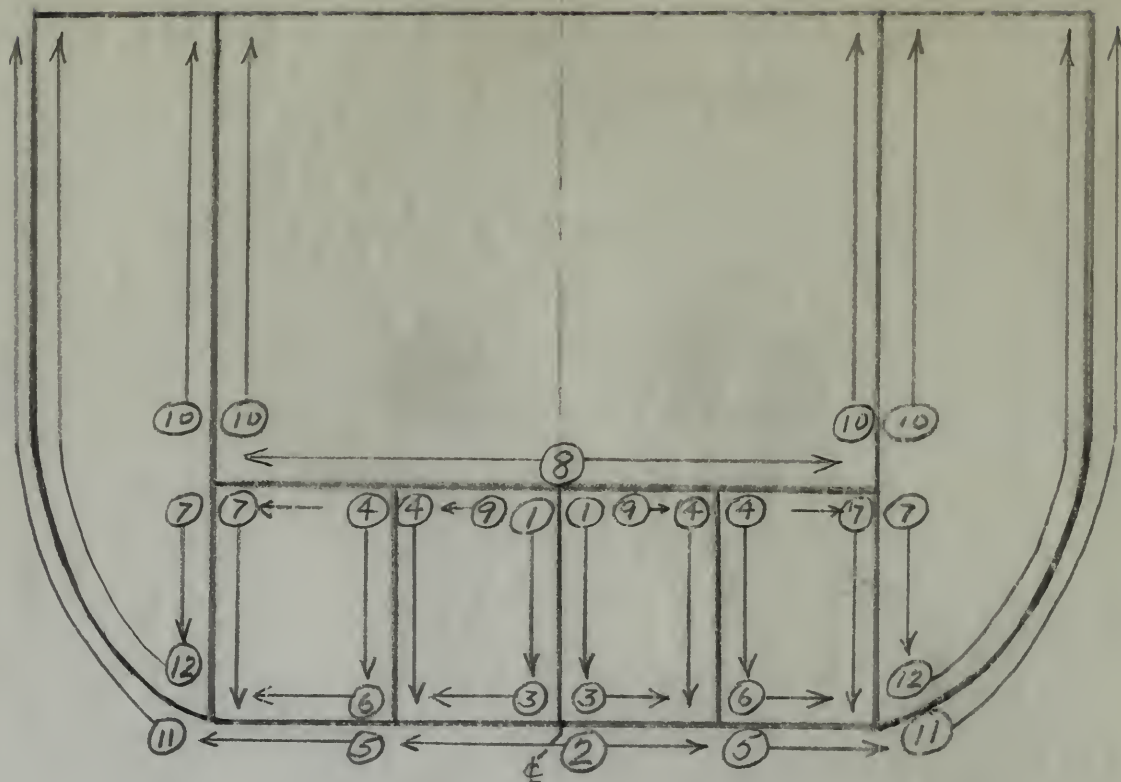
(see next page for sketch.)

about welding of center or local sections. This
 time and all other factors especially. This
 part and statement simultaneously. In not least
 than more than the present need of welding.
 This suggests also through simultaneously.

Welding of the structure is both the vertical and the horizontal
 must be kept evenly balanced, and the welding of the vertical
 part must be evenly distributed from top to bottom to maintain
 alignment. This factor is done by the use of back-step welding.
 Part must be extended in reaching down for the point of the point
 where welding is being done or vice versa will result, but so
 the uneven distribution of stresses. Despite both ends, it is
 often necessary to have a level sub-assembly to offset con-
 traction between top and bottom of the main assembly.

The second example will illustrate one situation, in
 which two sections are joined together on the welding ways.
 The procedure presented here is typical of the full work done
 on the welding ways. It is to be remembered in this case that
 the bulkhead section shown is the boundary between two pre-
 fabricated hull sections and is thus in a vertical position,
 which provides the use of an automatic welding machine.

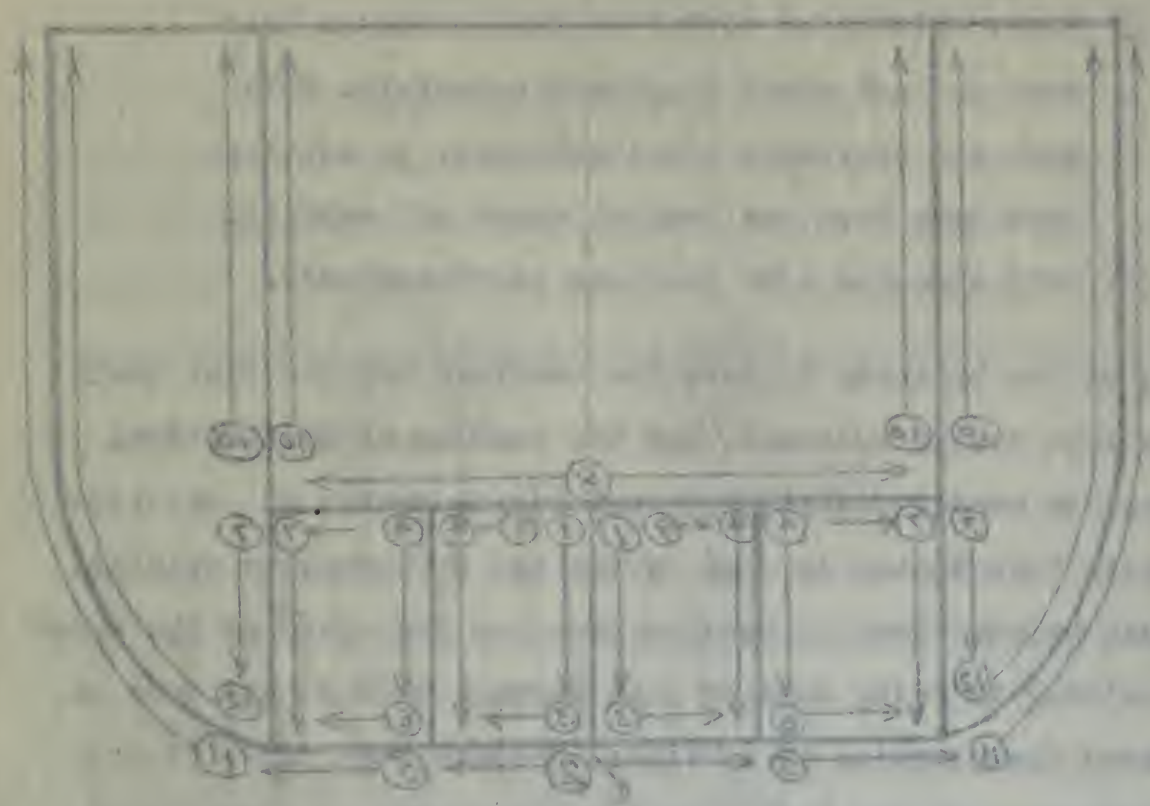
(see next page for details.)



All the above welding is to be done by the back-step method and by a pair of welders, working one on each side of the centerline. Note that the sequence is started at the keel. All the interior joints are made prior to welding the sides of the shell. It is important that all the internal welding in each section should be completed prior to the final assembly.

In the erection and welding of vessels of longitudinal construction, rather than the sectional construction noted in the second example above, the sequence is as follows:-

1. placing and welding of the keel assemblies on the keel blocks.
2. erection of the bottom shell with the butts of the plates being welded starting from



All the above welding is to be done by the back-step method and by a pair of welders, working one on each side of the centerline. Note that the sequence is started at the heel. All the interior joints are made prior to welding the sides of the shell. It is important that all the interior welding is made section above the completed plates so the final assembly

- is the attention and welding of vessels at localities.
- Domestication, which then the essential consideration must be the second example above, the sequence is as follows:-
1. Plating and welding of the hull assembly on the hull plates.
 2. erection of the bottom shell with the plates of the plates being welded starting from

amidships and working fore and aft, while the the longitudinal seams of the plates are restrained from getting out of alignment, by use of bolts or spacers.

3. erection of longitudinals and bulkheads (sub-assemblies).

4. erection and welding of the upper shell plating and main deck, taking similar precautions as in welding the bottom shell.

5. internal decks are then welded all around, after the shrinkage has taken place in the shell.

It should be pointed out that longitudinals, including decks, should never be restrained from contracting by tacking or welding them before the full transverse shrinkage has taken place. Sequence is extremely important in this effect. If there is a keel rise, there is internal or locked-up stress which, if detected in time, can be corrected by changing the welding sequence from a straight side to side band type of sequence to an angle in relation to the keel, by which is meant that lower levels are welded first (in going away from amidships) which will tend to draw the bow or stern down. The above discussion of a longitudinal designed ship applies more to a destroyer type vessel, in which the length to beam ratio is large.

Final Remarks:-

The importance of welding and erection sequence has been discussed with the particular aim of showing the scientific rea-

relationship and working time and etc., while the

the longitudinal means of the plates are not

affected from welding out of alignment, by

use of bolts or spacers.

3. removal of longitudinal and vertical (exp-

ansion).

4. removal and welding of the upper shell plate

ing and main body, taking other precautions

as to welding the bottom shell.

5. internal stress are then welded all around, af-

ter the expansion has taken place in the shell.

It should be pointed out that longitudinal, bending stress,

should never be relieved from contracting by welding or weld-

ing them before the full transverse expansion has taken place.

Expansion is extremely important in this respect. If there is a

shell with, there is internal or locked-up stress which, if the

released in time, can be corrected by changing the welding se-

quence from a straight side to side bend type of sequence to

an angle in relation to the shell, by which it is said that four

inches are added (that is going away from outside) - which

will tend to draw the top or bottom down. The above discussion of

a longitudinal designed with splices made to a doubler type

vessel, in which the length is less than is large.

Final Remarks:

The importance of welding and expansion sequence has been

discussed with the intention of showing the relative pro-

soning upon which its development is based and to present some idea of its application in modern shipbuilding. The principles of step-back and starting from the center and working outboard, are utilized in the final assembly of the ship, as well as in the welding of its components. Without the knowledge of sequence, ship construction on semi-assembly line methods would be out of the question.

nothing upon which the Government is based and no ground
basis of the application for evidence is established. The evidence
is at best a mere statement from the owner and nothing more,
and is not in the final judgment of the ship, as will be
the result of its examination. Without the knowledge of the
ship's management and crew, it is not possible to set
the question.

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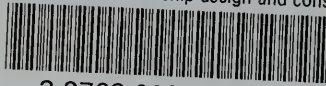
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